CrIS Radiometric Calibration: Uncertainty Estimates and Evaluations

On behalf of the CrIS SDR Cal/Val team

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SUOMI NPP SDR Science and Validated Product Maturity Review
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Outline

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  - On-orbit RU estimates
  - Other terms
- **Nonlinearity Refinements**
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  - Clear sky Obs-Calc
- **Continuing Work**
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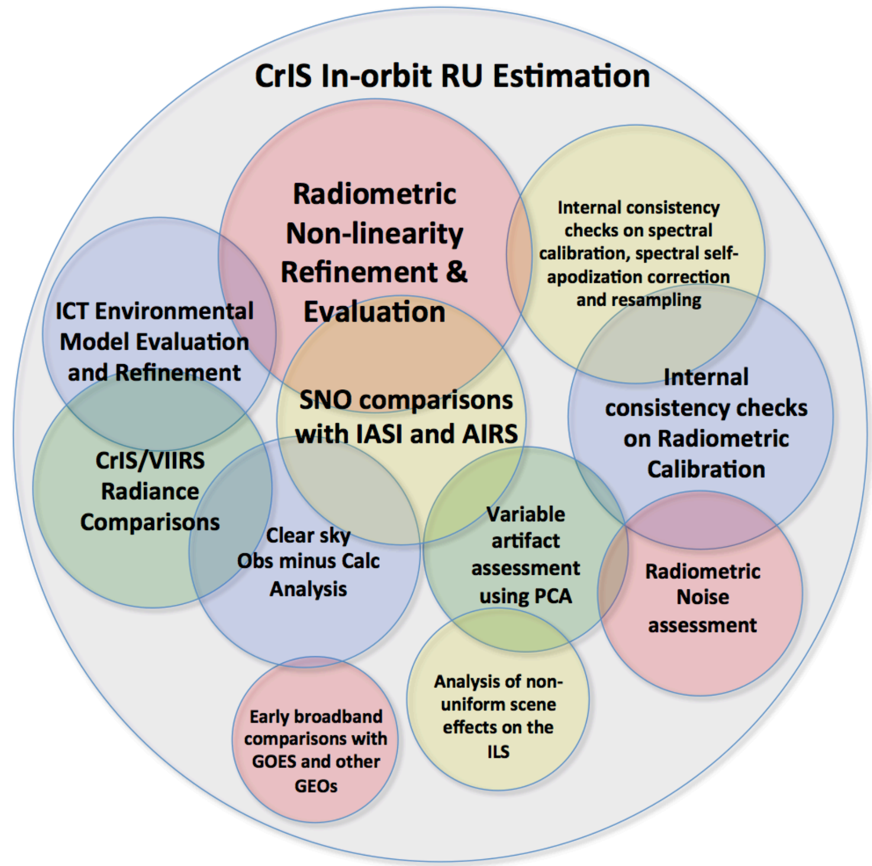
  - SW band biases
- **Summary and Conclusions**



Radiometric Uncertainty (RU) Estimates

- Perturbation of Calibration Equation and Parameter uncertainties
- On-orbit RU estimates
- Other terms

➢ Required in order to understand the size and dependencies of the primary contributors to the CrIS SDR uncertainties, for calibration improvements, weather, process, trend, and inter-calibration applications.

Radiometric Uncertainty Estimates

Simplified On-Orbit Radiometric Calibration Equation:

$$R_{scene} = \mathcal{Re}\{(C'_{scene} - C'_{SP}) / (C'_{ICT} - C'_{SP})\} R_{ICT} \quad \text{with:}$$

Nonlinearity Correction: $C' = C \bullet (1 + 2\, a_2\, V_{DC})$

ICT Predicted Radiance: $R_{ICT} = \varepsilon_{ICT}\, B(T_{ICT}) + (1-\varepsilon_{ICT})\, [\, 0.5\, B(T_{ICT,\, Refl,\, Measured}) + 0.5\, B(T_{ICT,\, Refl,\, Modeled})]$

Parameter Uncertainties:

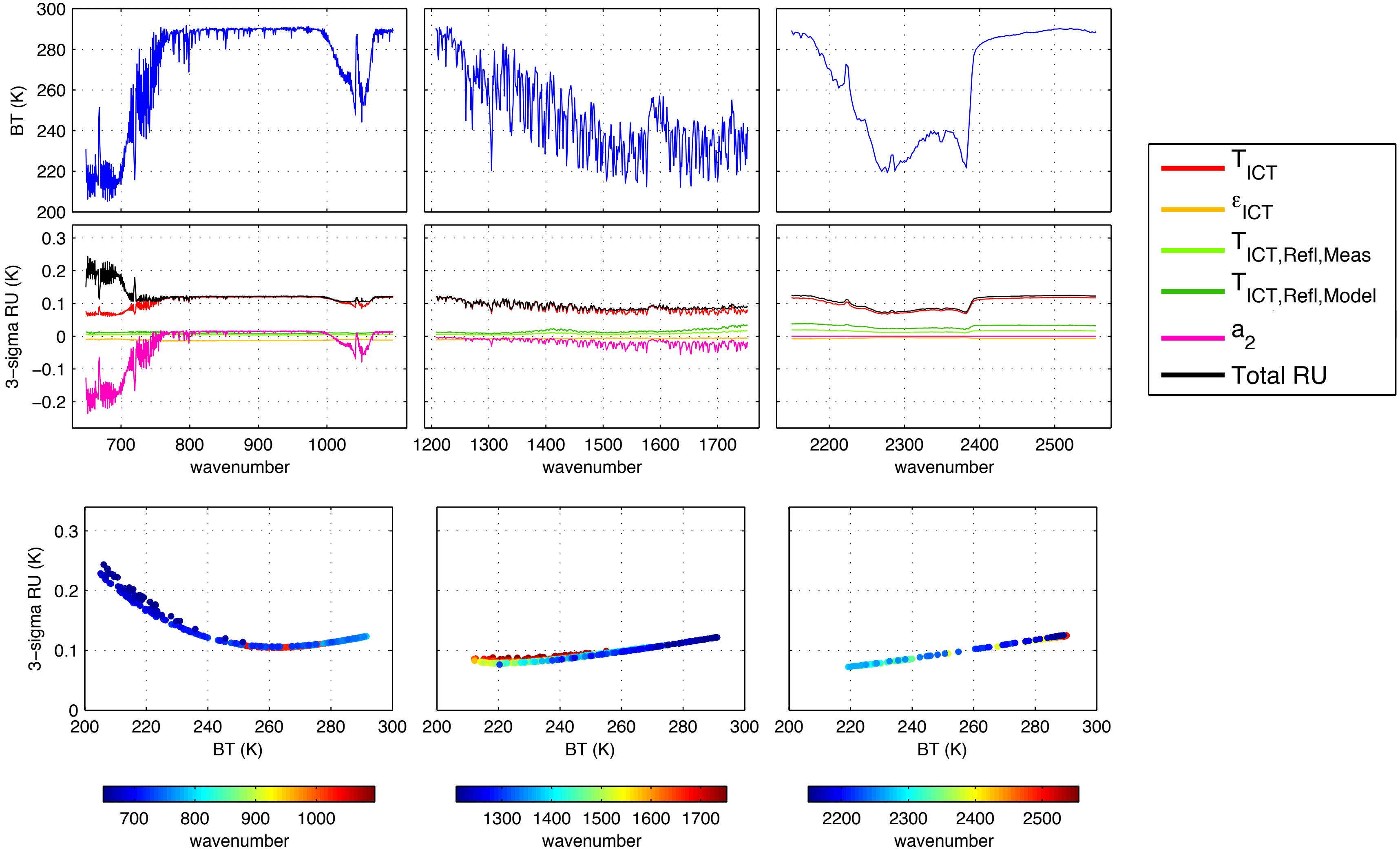
Parameter	Nominal Values	3-σ Uncertainty
T_{ICT}	280K	112.5 mK*
ε_{ICT}	0.974-0.996	0.03
$T_{ICT,\, Refl,\, Measured}$	280K	1.5 K
$T_{ICT,\, Refl,\, Modeled}$	280K	3 K
a_2 LW band	0.01 – 0.03 V^{-1}	0.00403 V^{-1}
a_2 MW band	0.001 – 0.12 V^{-1}	0.00128 – 0.00168 V^{-1}

**Exelis at-launch estimate*

Following *Tobin et al. (2013), Suomi-NPP CrIS radiometric calibration uncertainty, J. Geophys. Res. Atmos., 118, 10,589–10,600, doi:10.1002/jgrd.50809.*

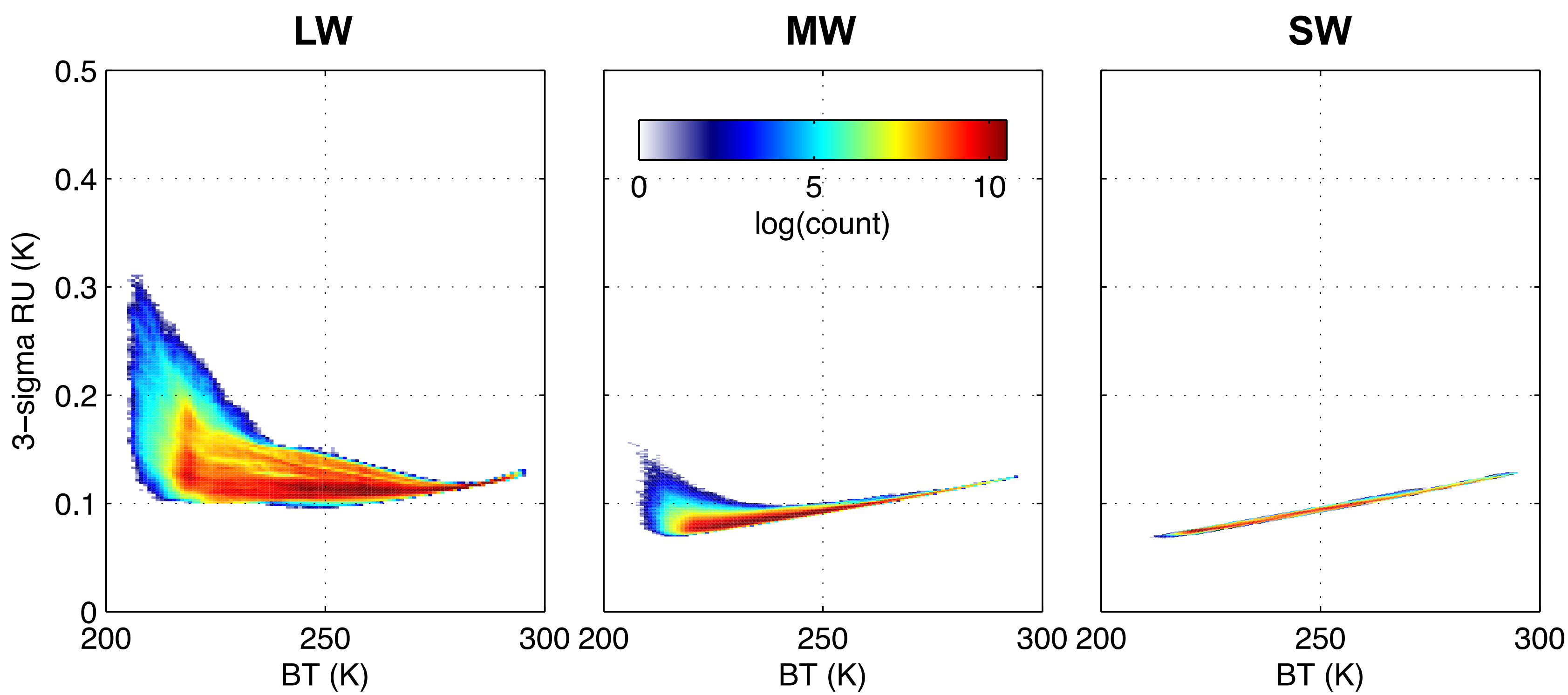
Example 3-sigma RU estimates

For a typical warm, ~clear sky spectrum



Example 3-sigma RU estimates

Log scale RU distributions for one orbit of CrIS Earth view data, including all FOVs and spectral channels within the band:



- Uncertainties are greatly reduced due to re-analysis of the TVAC data and on-orbit FOV-2-FOV analysis. In particular, MW band uncertainties are greatly reduced due to the high degree of linearity of MW reference FOV9.
- Overall, RU is <0.3K (LW), <0.15K (MW), <0.15K (SW): Better than spec by approximately a factor of 4.

Other Terms

Smaller contributors not currently accounted for in the calibration algorithm or included in current RU estimates:

- Spectral Ringing
- Polarization
- Possible SW Nonlinearity

Addressed in later slides

- Other smaller/negligible terms:
  - Detector temperature changes, Changes in DA Bias tilt over 4 minutes, Changes in optical flatness, OPD sample rate drift over 4 minutes, Electronic gain drift over 4 minutes, Electronic delay drift over 4 minutes, FOV to FOV crosstalk in same band, FOV to FOV crosstalk between bands, Stray light, Optics temperature change during cal, Changes in channel spectra

Nonlinearity Refinements

- Motivation and Methodology, and changes to NLC equation and coefficients
- Reprocessed dataset
- Example changes in calibrated spectra

Nonlinearity Refinements

(Refinements developed since the Provisional Review)

Motivation

- To provide improved traceability of the Nonlinearity algorithm and coefficients to the CrIS TVAC External Calibration Target residuals and analysis.
- This is most important for the LW band where all FOVs display a significant level of nonlinearity, and less so for the MW band where some FOVs display high levels of linearity and can be used as an in-orbit reference to assess the other MW FOVs.

Methodology

- **Involves determination of the a_2 nonlinearity coefficients (other NL related terms are relatively well known):**
    1. Initial values determined from analysis of TVAC ECT view data.
    2. Change from pre-launch to in-orbit estimates based on analysis of Diagnostic Mode data (out-of-band harmonics), leading to initial in-orbit values.
    3. Followed by the selection of a reference FOV and adjustments of a_2 values for the remaining FOVs to create optimal agreement with the reference FOV for Earth view data

Resulting changes to the NLC equation and coefficients

- New a_2 values (with respect to current operational values, includes an overall increase for all LW FOVs, along with smaller refinements to improve FOV-2-FOV agreement for LW and MW bands)
- Equation change from $C' = C / (1 - 2a_2V)$ to $C' = C \bullet (1 + 2a_2V)$
- New modulation efficiency (e_{mod}) values

Reprocessed Dataset

The refined CrIS SDRs for the full mission are available at:

ftp://peate.ssec.wisc.edu/allData/products/results/cris/cspp/SDR_1_4b_ILS_NLC_v33a-04/

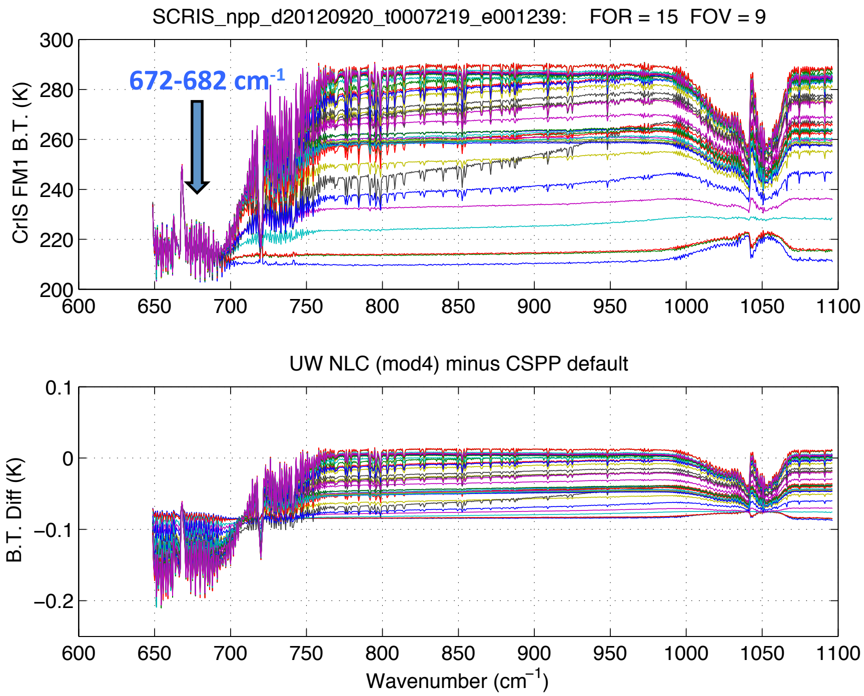
Differences with respect to the operational IDPS dataset:

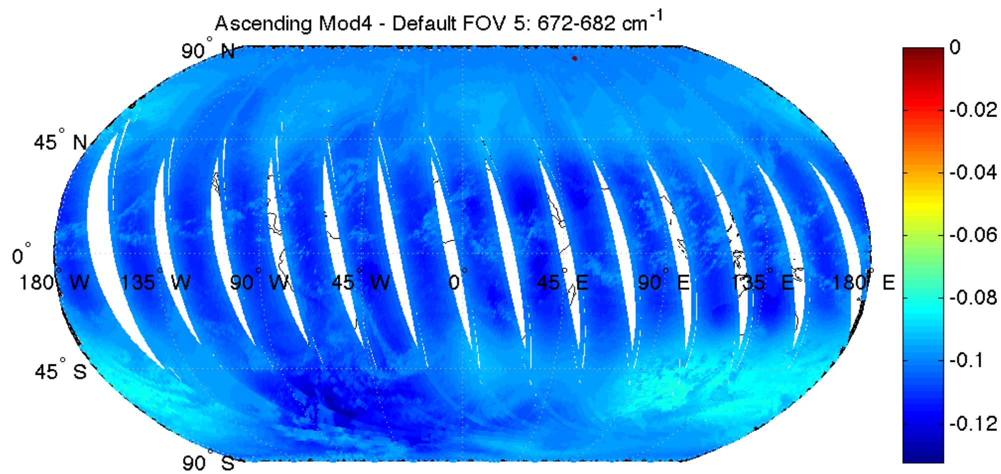
1. Includes Nonlinearity algorithm and coefficient refinements*
2. Includes ILS algorithm and coefficient refinements*
3. Includes consistent SDR algorithm processing for the full mission
4. Processing takes place with ~24 hour latency to avoid missing packet issues

*** The same Nonlinearity and ILS refinements are expected to be implemented in IDPS processing with MX8.1 and EPv36 in February 2014.**

Evaluations of the CrIS RU presented here use the reprocessed dataset. Some example differences with respect to the operational IDPS processing are shown on the following slides.

Example changes:
New versus Old Nonlinearity Correction



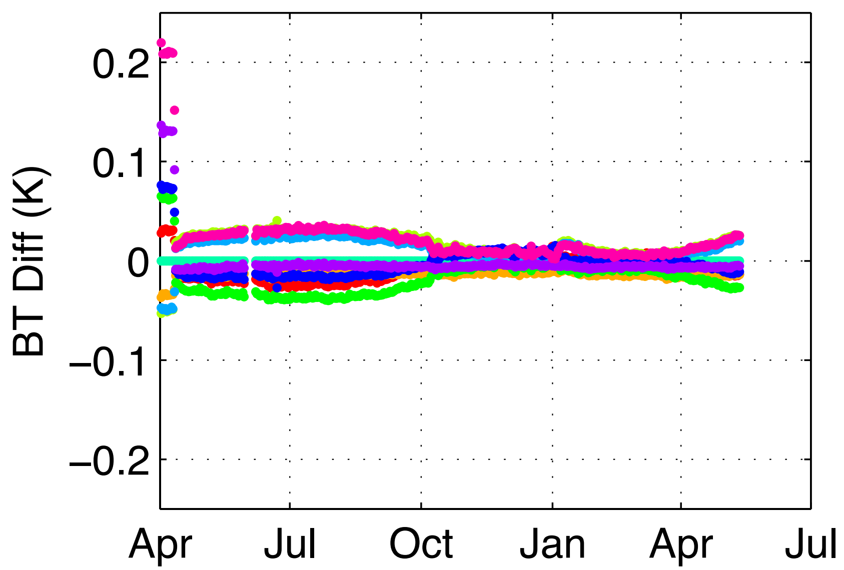


- LW stratospheric channels shift to colder brightness temperatures (order ~0.1K) everywhere.
- For cold scenes, LW window channels also shift to colder brightness temperatures.

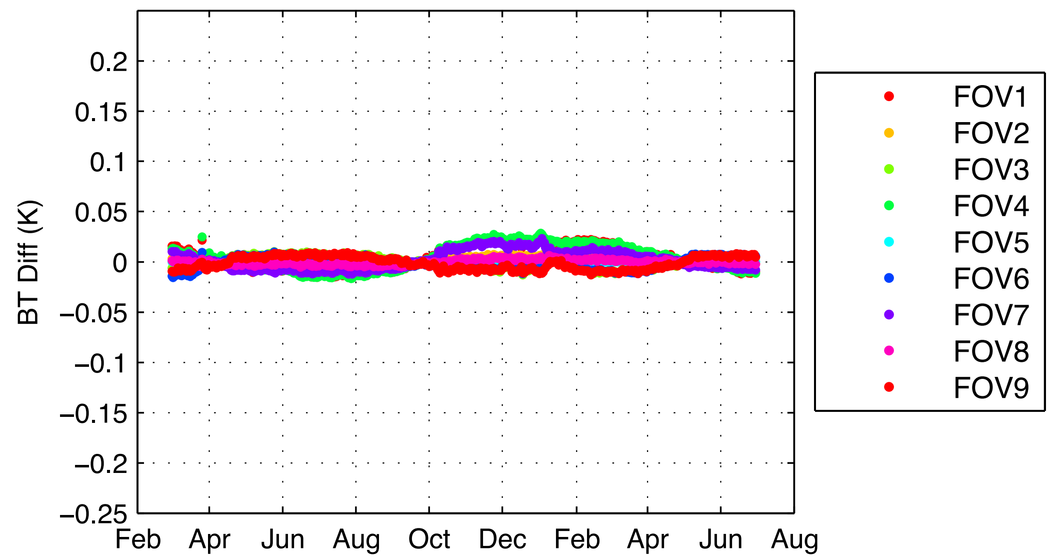
Example changes: Long term FOV-2-FOV differences

LW (672-682 cm^{-1}) BT Differences with respect to FOV5

IDPS processing



Reprocessed



- Reprocessing with the NLC refinements removes the inconsistencies in the IDPS time series and also minimizes the magnitude of FOV-2-FOV differences.

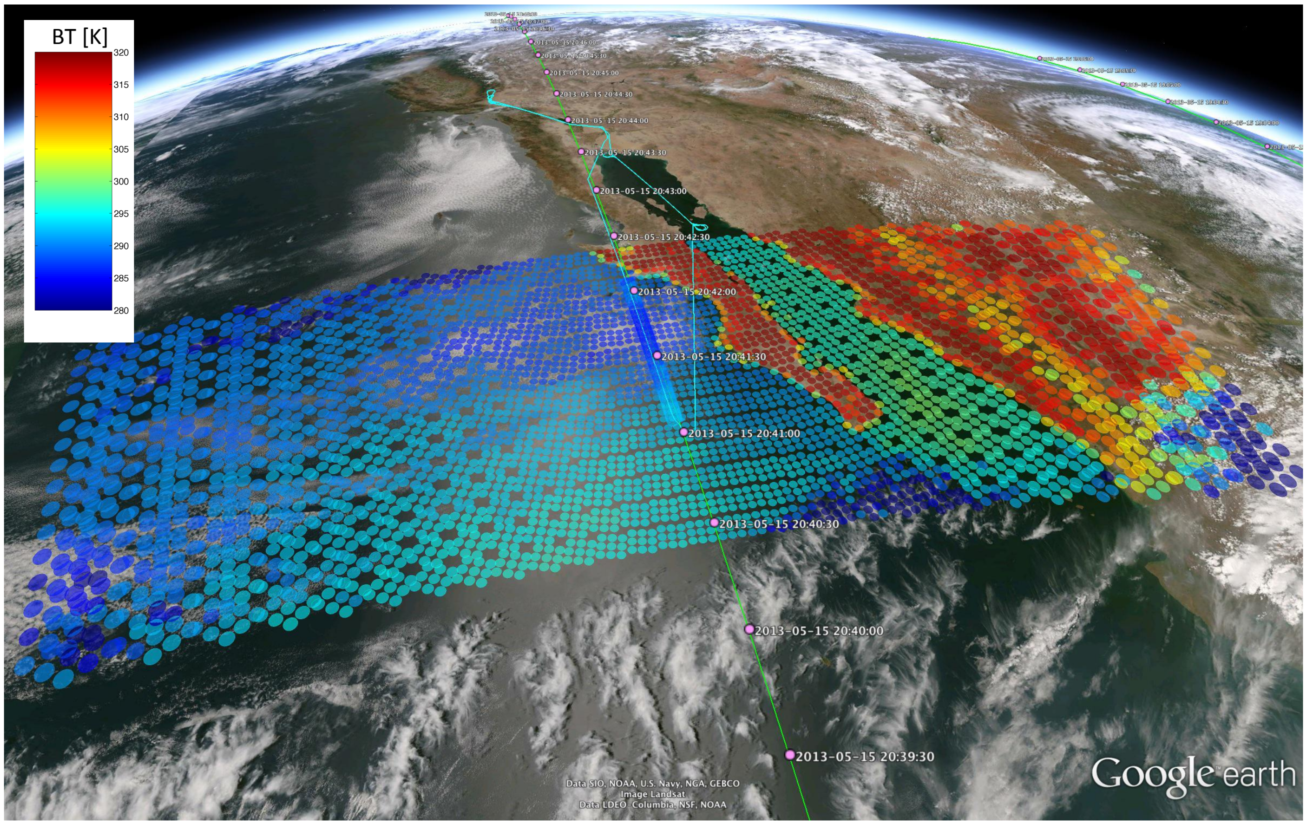
Evaluations of RU estimates
("Cal/Val")

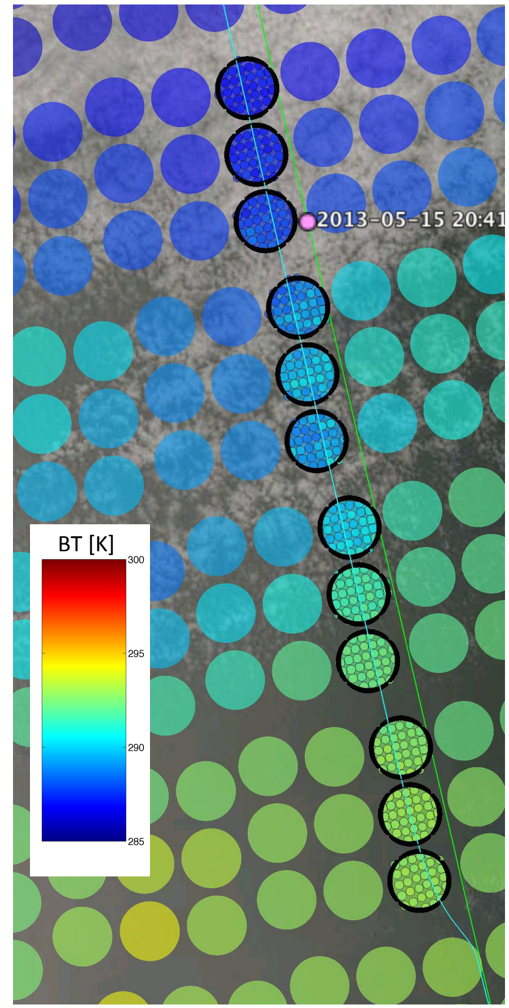
- Aircraft underflights
- CrIS/VIIRS comparisons
- CrIS/IASI comparisons
- CrIS/AIRS comparisons
- Clear sky Obs-Calc

➢ A range of techniques, with various levels of uncertainty/statistics/traceability, to assess the CrIS SDRs and associated RU estimates.

May 2013 Suomi-NPP JPSS Aircraft Campaign

Scanning-HIS evaluations of CrIS Calibration

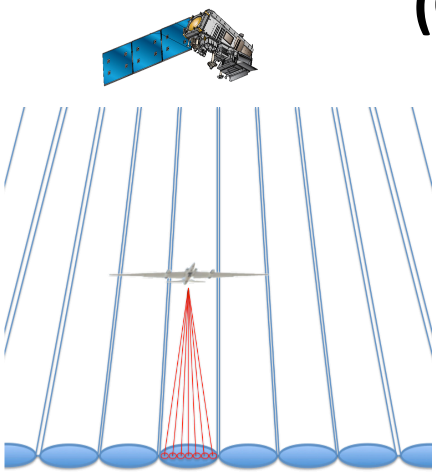


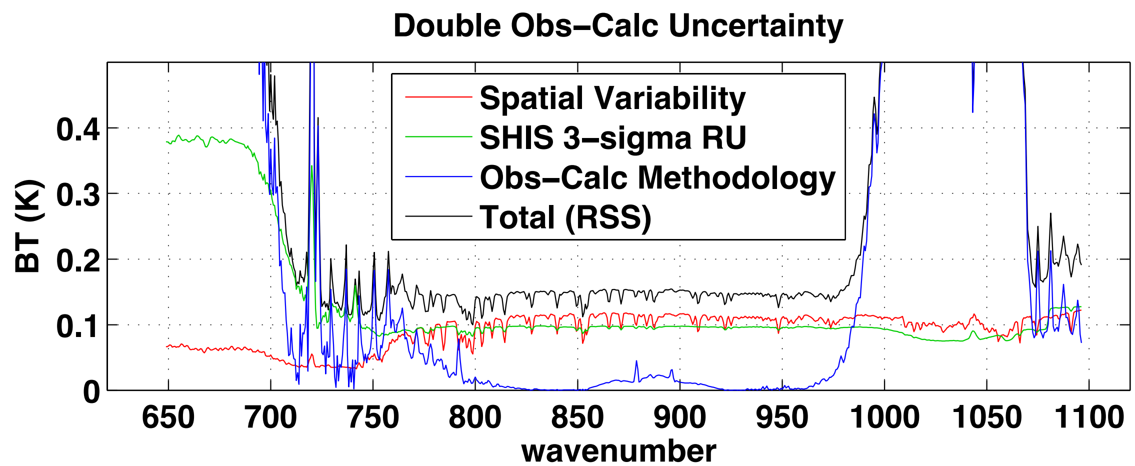


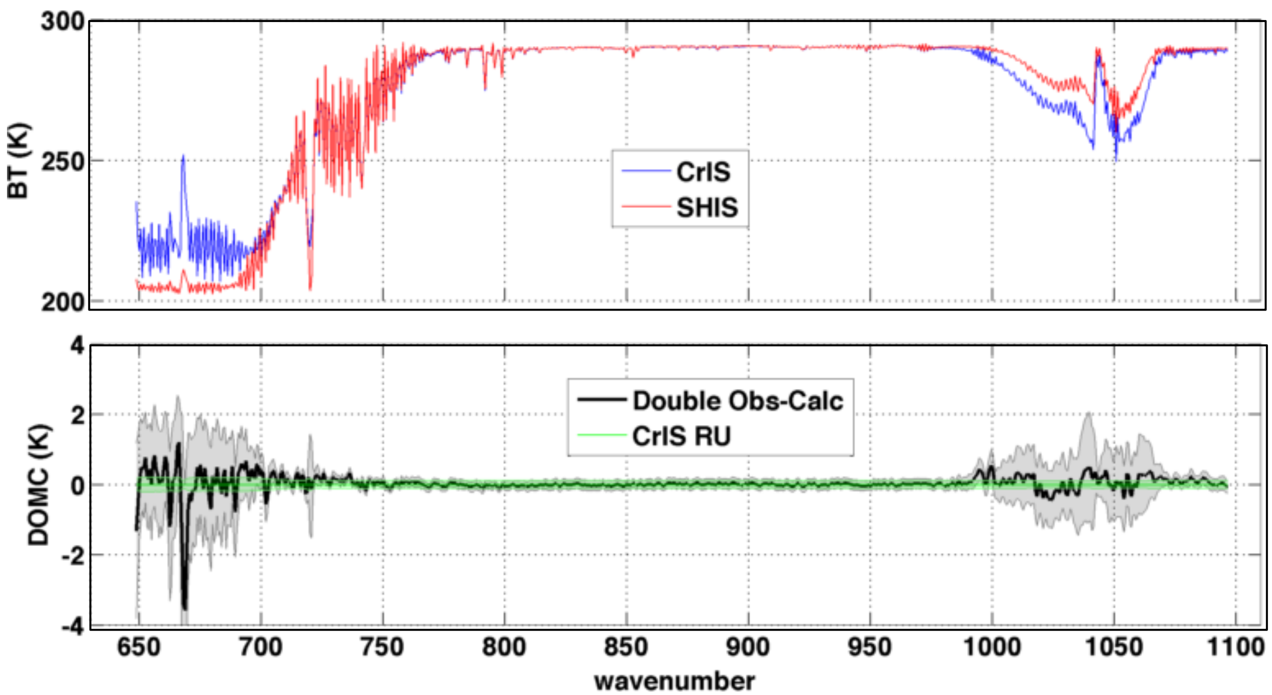
May 15 Underflight example:
S-HIS and CrIS 895–900 cm^{-1} BTs overlaid on VIIRS true color image

Double Obs-Calc Comparison Methodology and Uncertainty

$(CrIS_{obs}\text{-}CrIS_{calc})\text{-}(SHIS_{obs}\text{-}SHIS_{calc})$



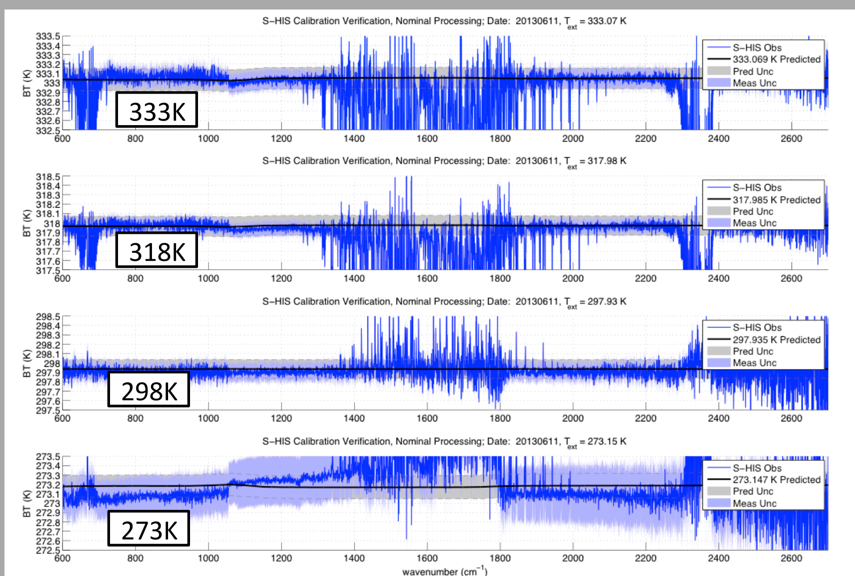




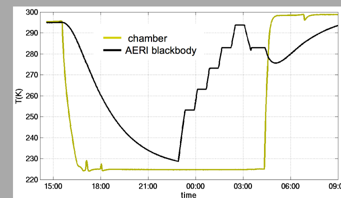
S-HIS Calibration, Calibration Verification, and Traceability

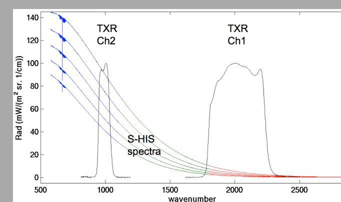
- Pre and post deployment end-to-end calibration verification
- Instrument calibration during flight using on-board calibration blackbodies
- Periodic end-to-end radiance evaluations under flight-like conditions with NIST transfer sensors

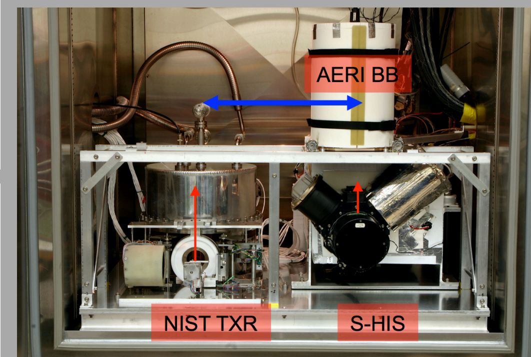
Post SNPP End-to-End Calibration Verification

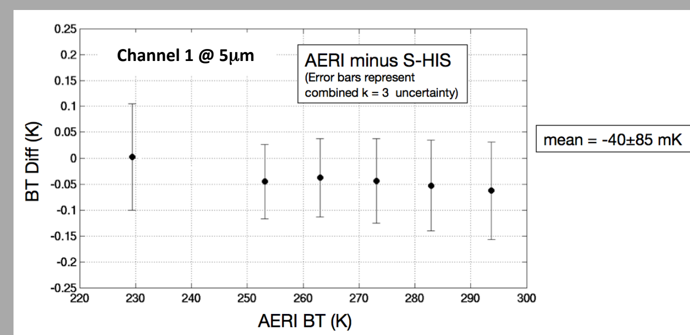


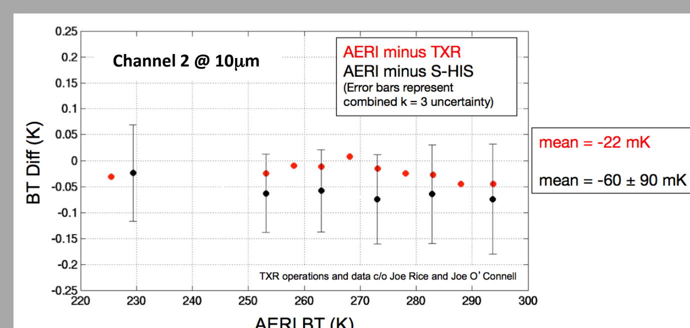
NIST TXR Validation of S-HIS Radiances





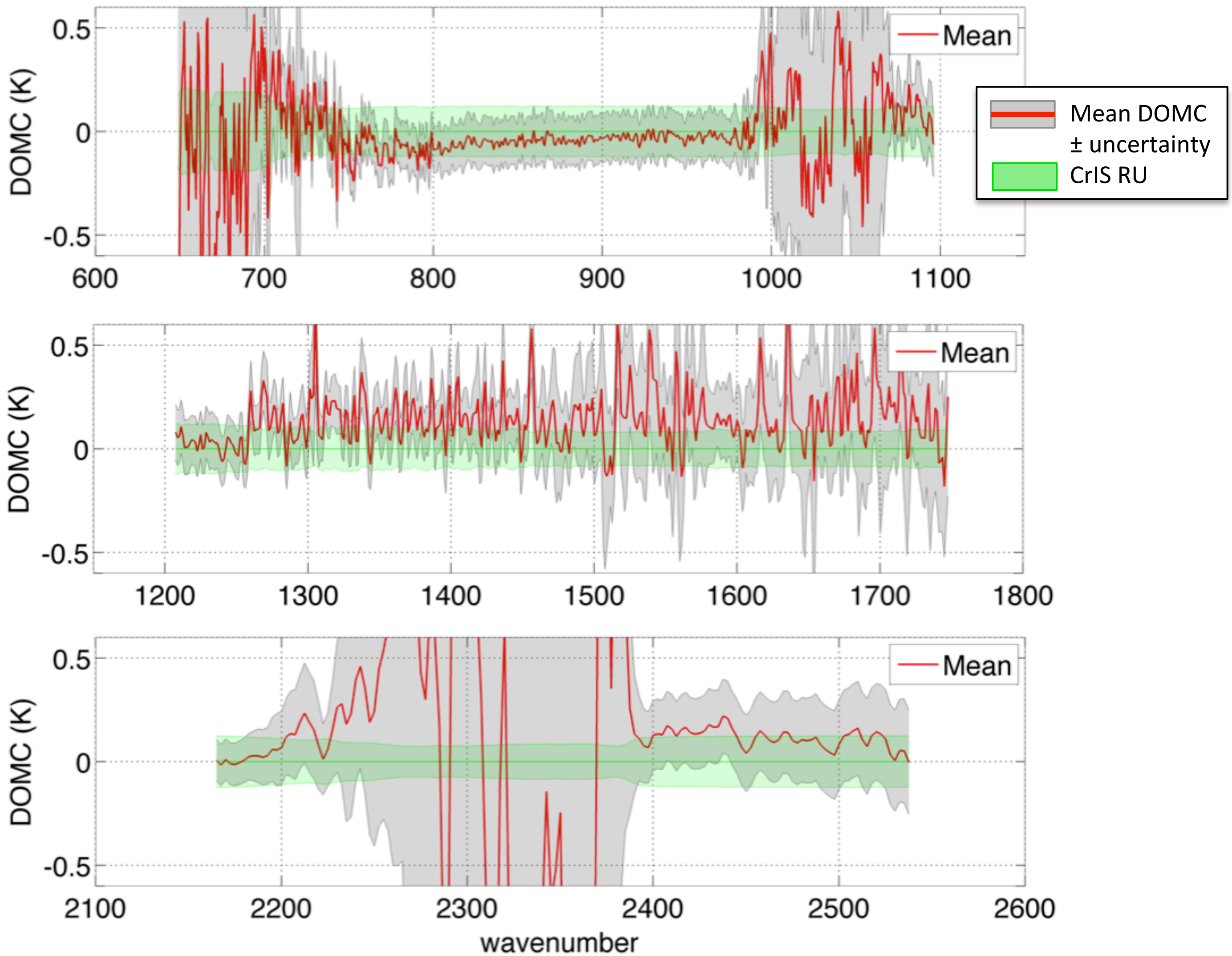






CrIS/S-HIS Underflight Results

Hamming apodization

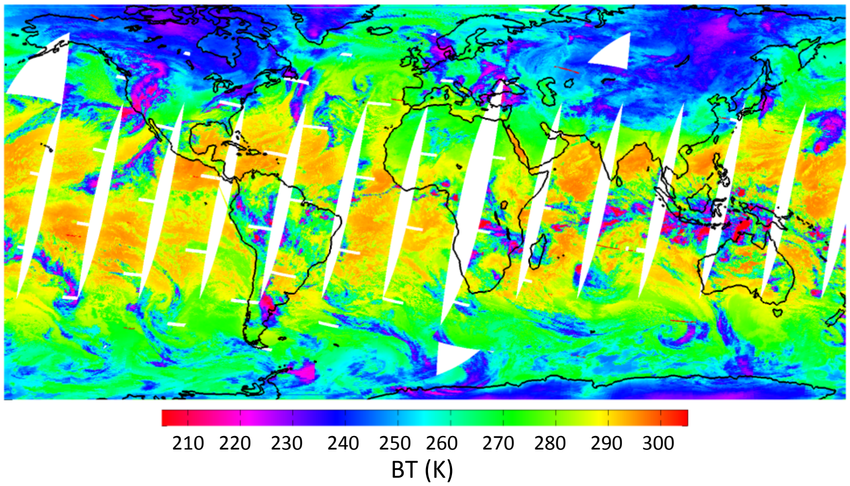


- Aircraft underflights provide periodic end-to-end verification of CrIS RU estimates with 0.1-0.2K uncertainty over most of the spectrum.

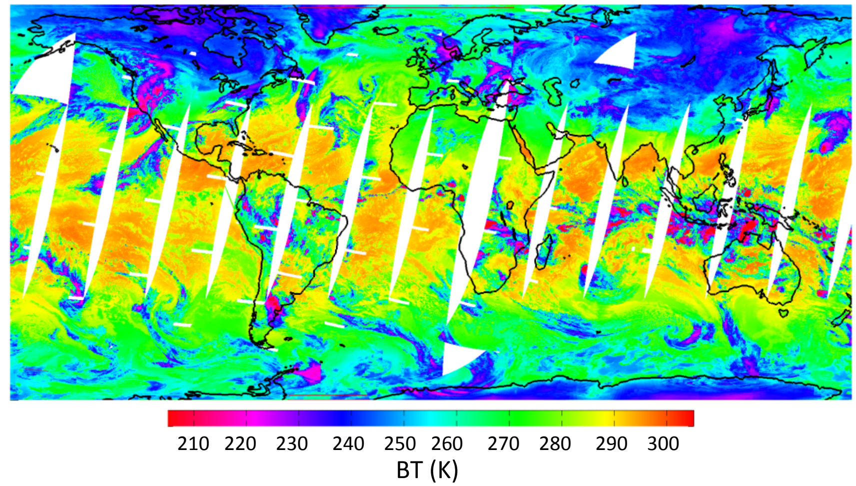
CrIS/VIIRS comparisons

Example Daily Comparisons, M15 band @ 10.8μm, Descending

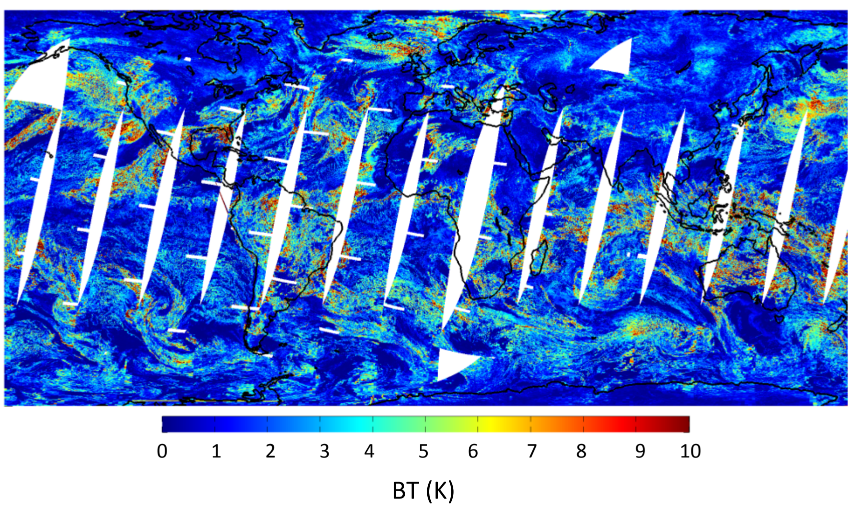
CrIS convolved with VIIRS SRF



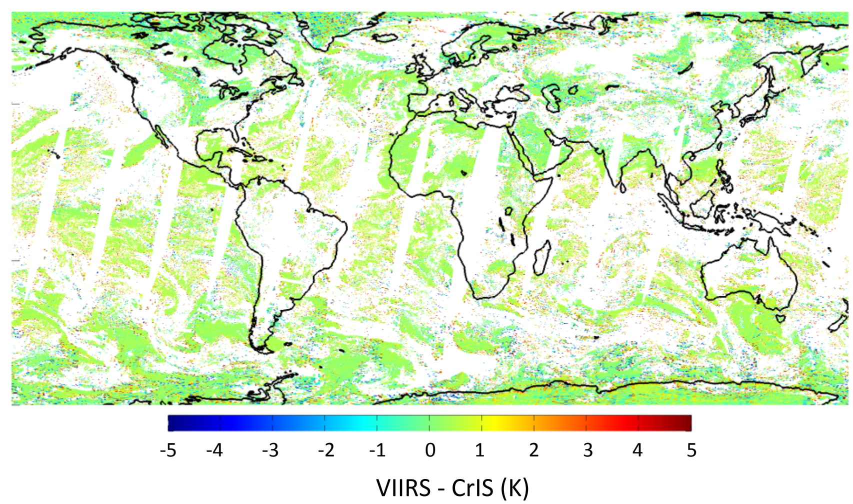
VIIRS mean within CrIS FOVs



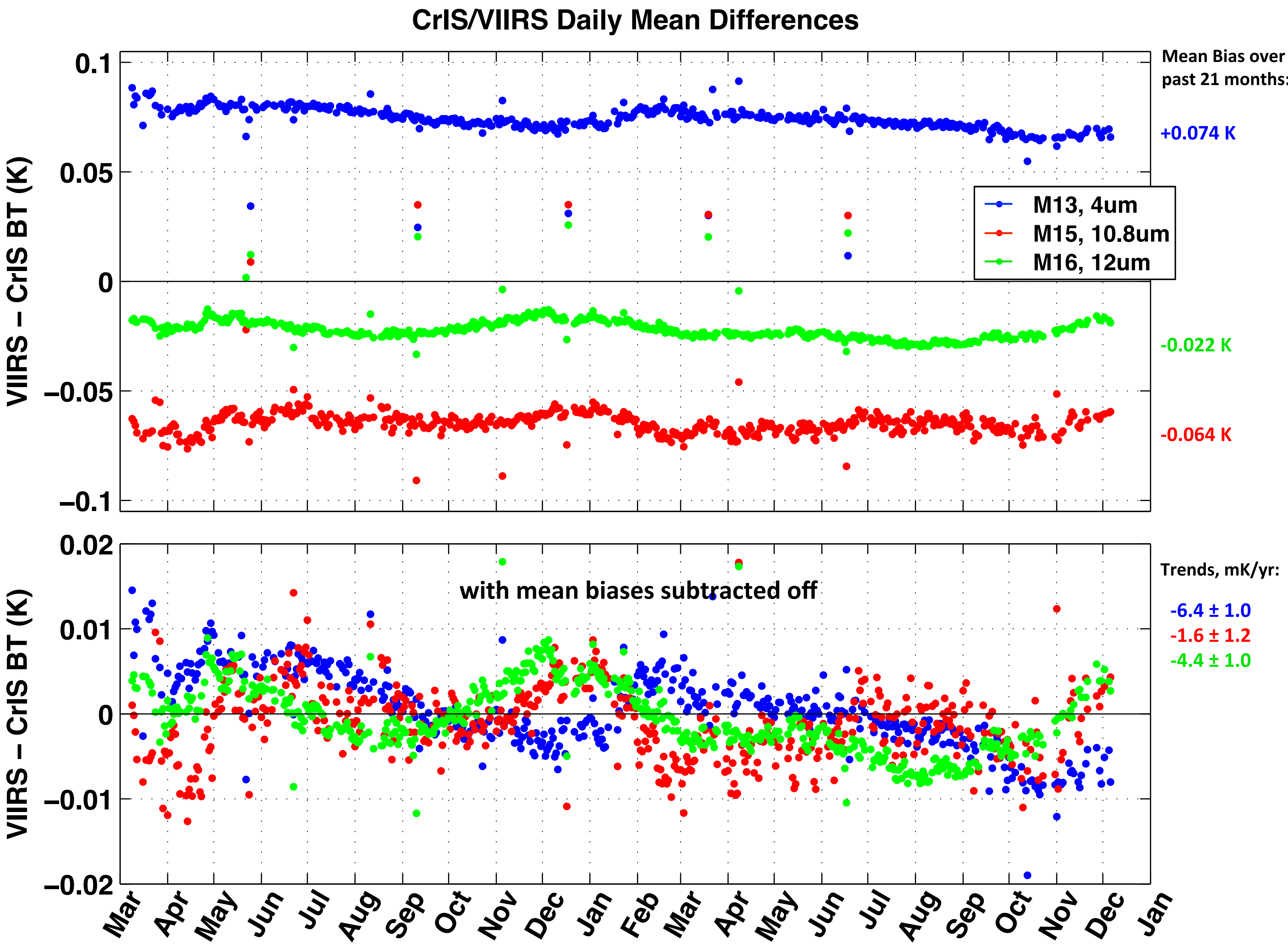
VIIRS standard deviation within CrIS FOVs



Differences for uniform scenes

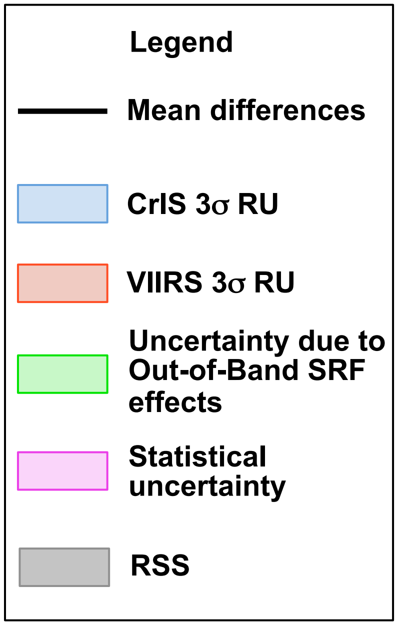


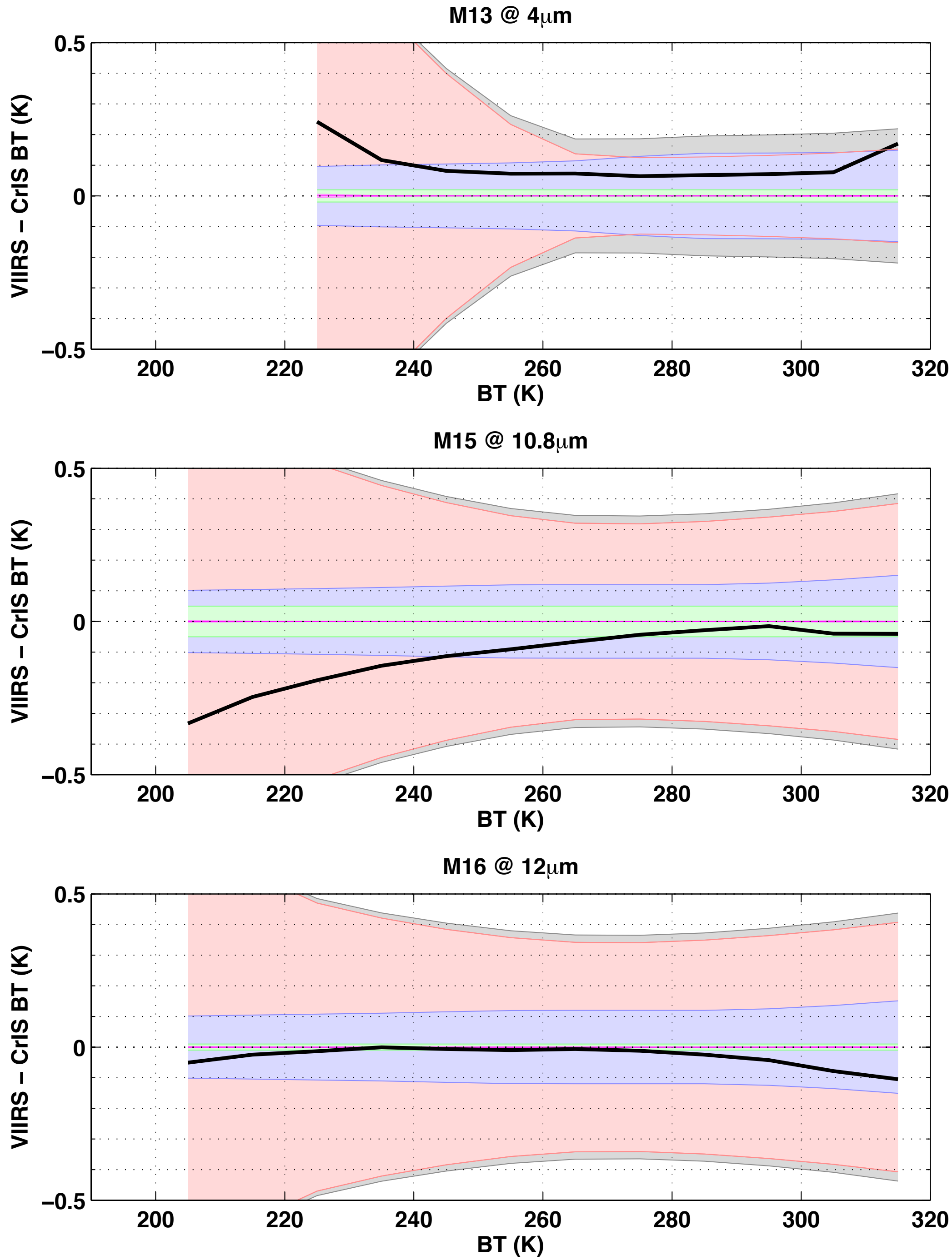
- Each day includes ~500,000 colocations which pass a spatial uniformity test



- CrIS/VIIRS daily mean differences are < 0.1K and trends are < 10 mK/yr

CrIS/VIIRS comparisons with uncertainties

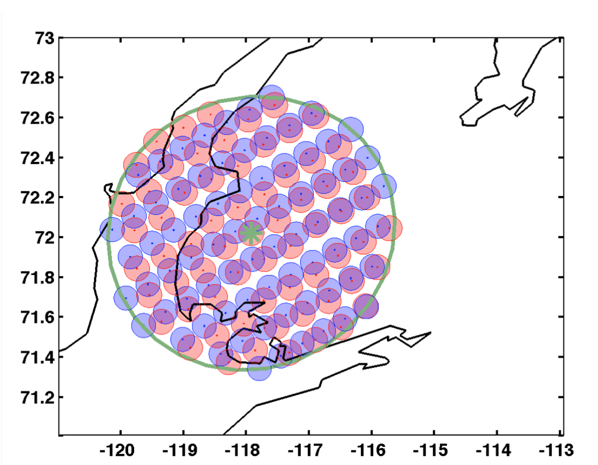




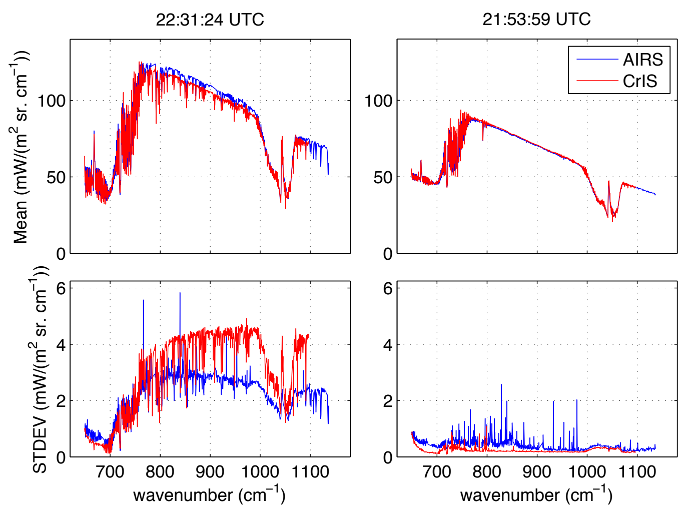
- VIIRS RU estimates provided by Jeff McIntire et al.
- CrIS/VIIRS differences are bounded by combined RU for all scene temperatures
- Larger VIIRS RU for cold scenes at M15 and M16 are due to c0 offset term and under investigation by the VIIRS SDR team.

SNO Comparison Methodology

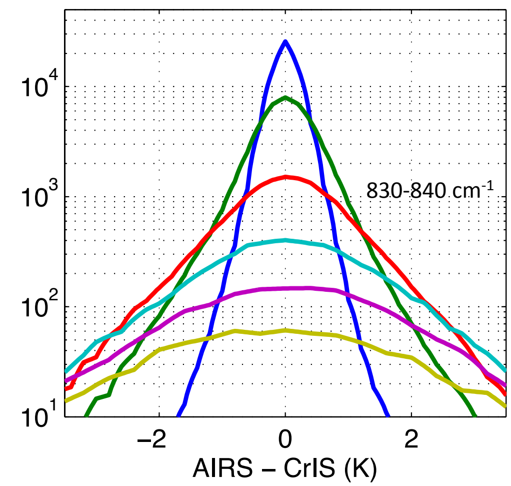
The SNO comparison technique is aimed at minimizing differences in the spatial/temporal collocation process and providing well understood uncertainties to identify persistent biases between two sensors.



A sample SNO showing CrIS and AIRS footprints within 100 km of the SNO location.



LW mean and standard deviation spectra for two example SNOs collected on 20120816.

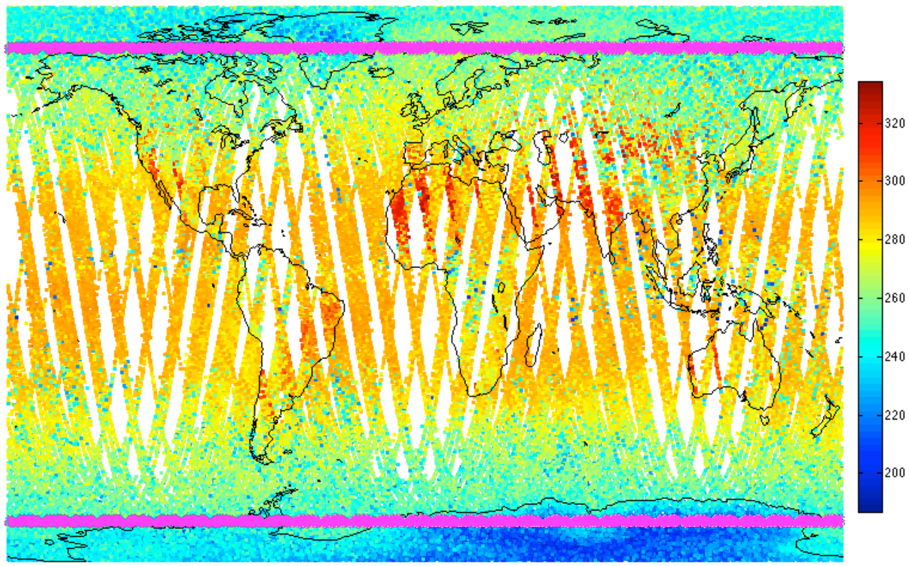


Collocation difference distributions for a large ensemble of SNOs for various ranges of spatial variability.

SNO Datasets

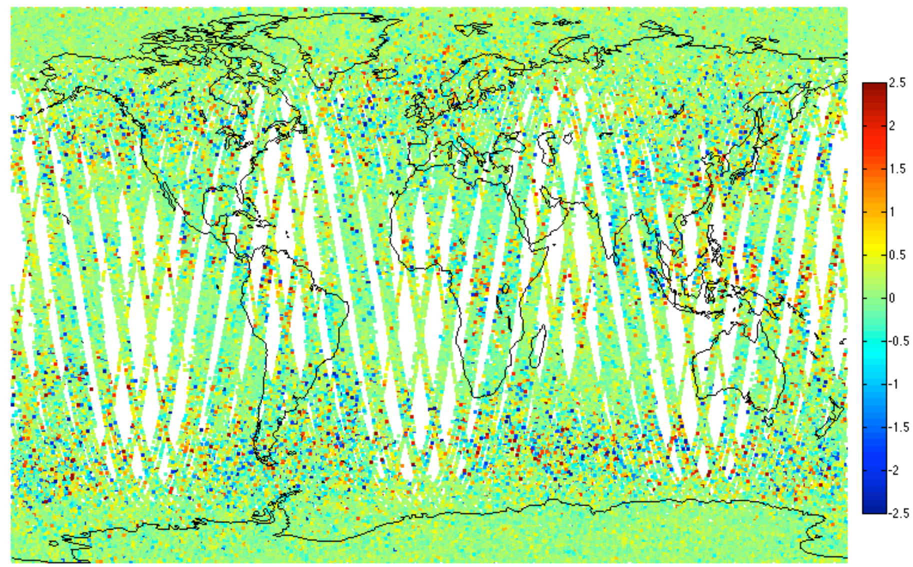
CrIS/AIRS: 1.2M "Big Circle" SNOs collected to date (March 2012 to Nov 2013); 20 minute window; -30 to 30 deg scan angle, <=2 deg scan angle diff. AIRS V5 L1B; CrIS ADL/CSPP SDR_1.4b_NLC_ILS

2510 cm^{-1} CrIS/AIRS SNO BTs



CrIS/IASI SNO locations

835 cm^{-1} CrIS/AIRS SNO BT Diffs

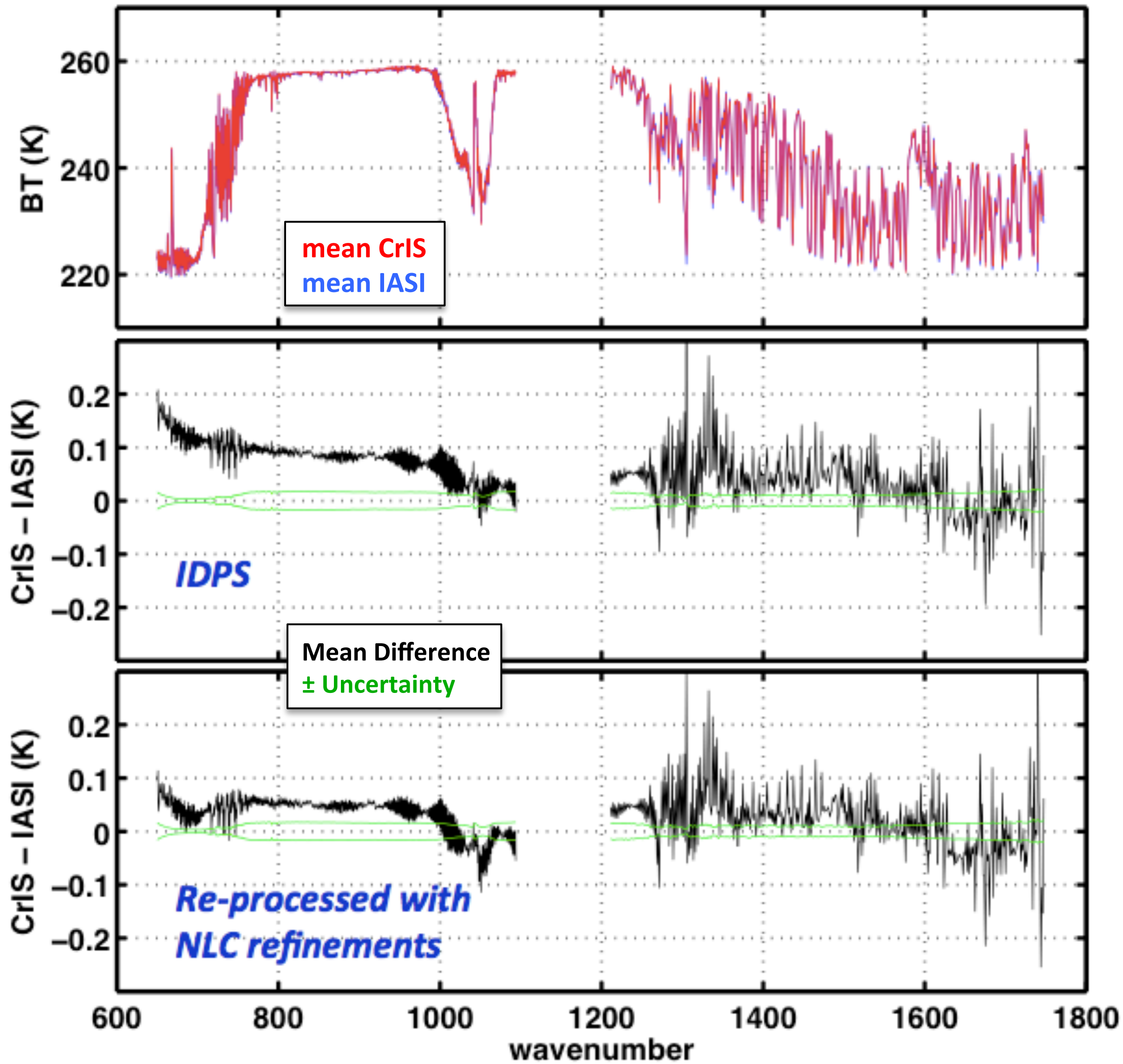


CrIS/IASI-A: 5270 "Big Circle" SNOs collected to date (March 2012 to Nov 2013); 20 minute window; nadir. ~20 days of coincidences, ~30 day gaps, ~half at +72.4 deg, ~half at -72.4 deg. IASI_xxx_1C_M02; CrIS ADL/CSPP SDR_1.4b_NLC_ILS

CrIS/IASI Northern SNOs

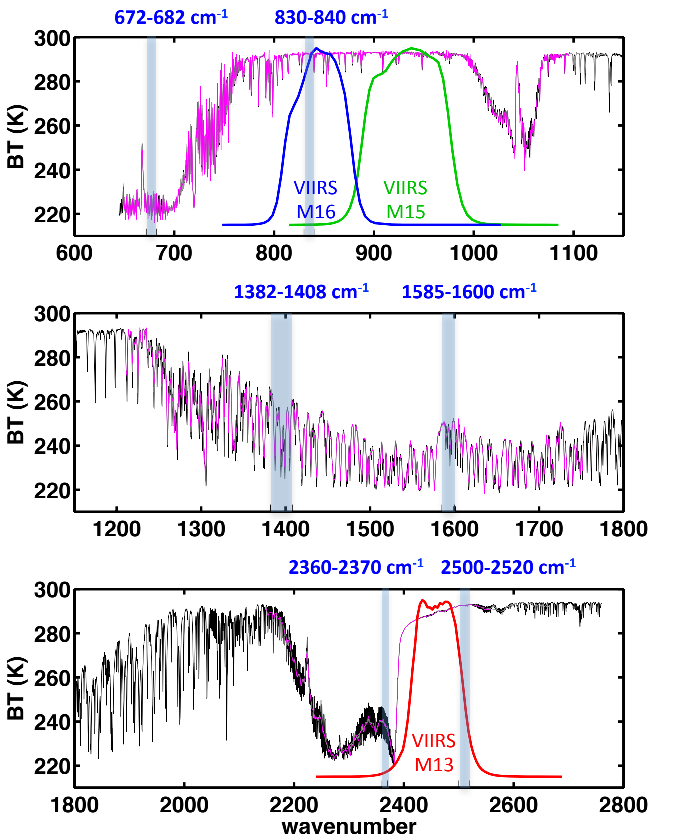
Hamming apodization

- ➢ Results shown for IDPS processing and with the reprocessed dataset including the NLC refinements presented earlier.
- ➢ Differences of ~0.2K or less
- ➢ NLC refinements:
  - Improved agreement in the LW band.
  - Negligible changes in the the MW band (as expected).

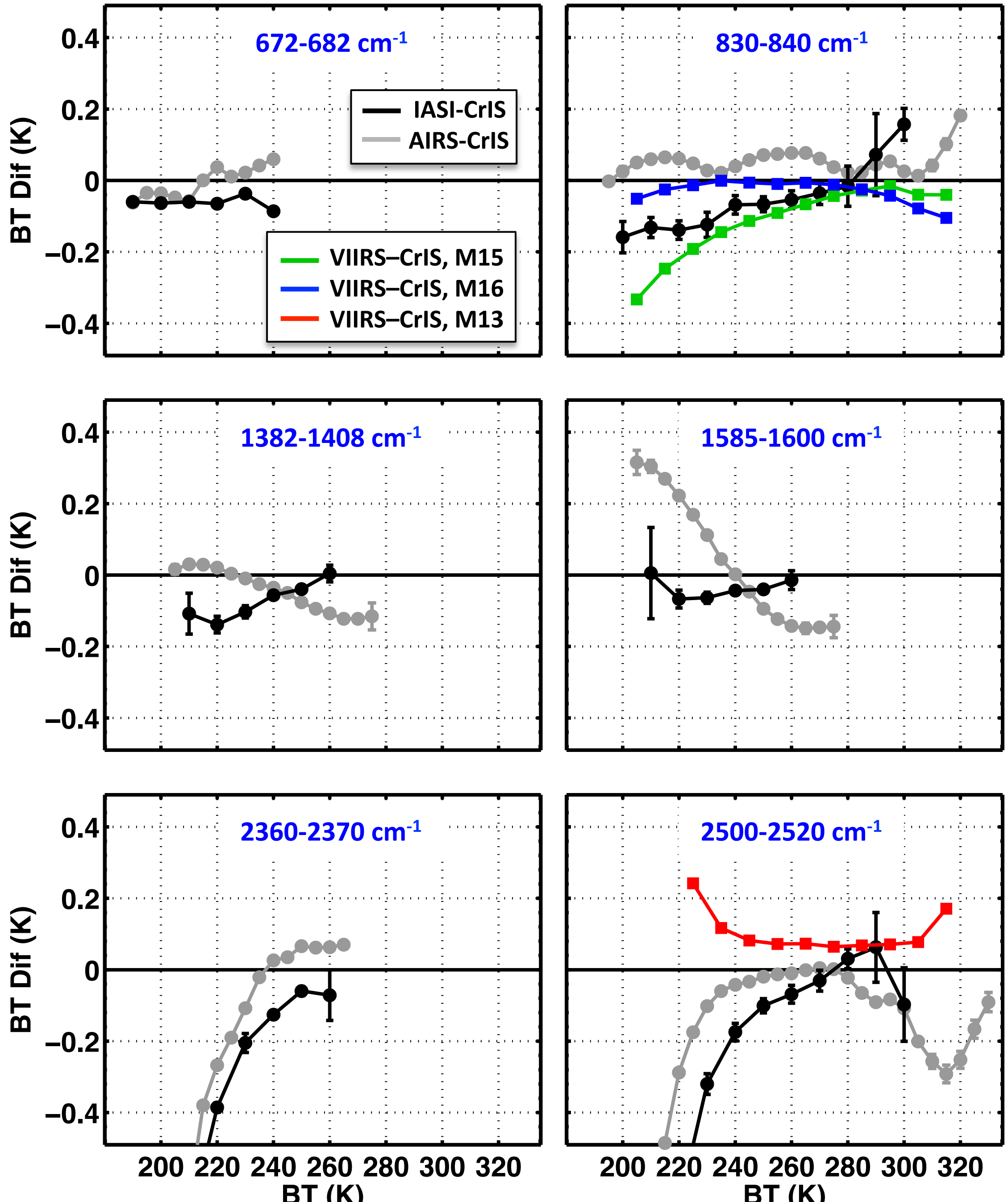


Summary of SNO results

for 6 representative spectral regions, and VIIRS/CrIS comparisons:



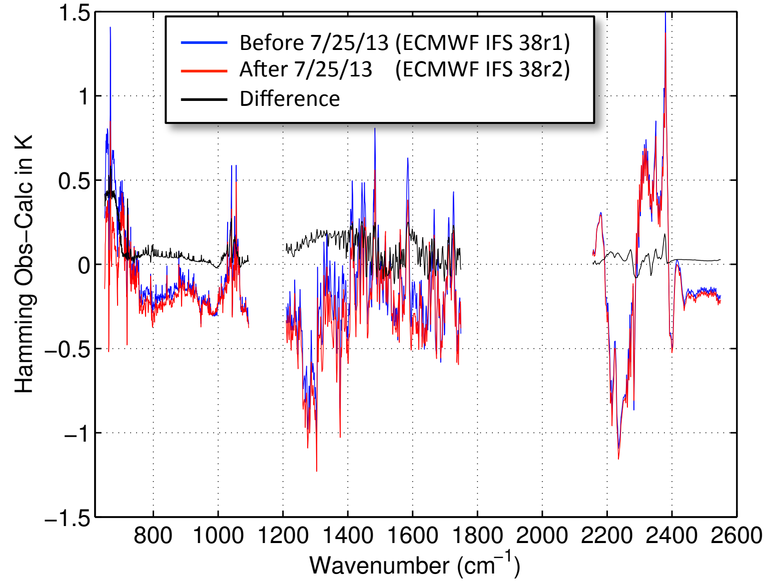
- LW differences display only small dependence on scene BT for both IASI and AIRS SNOs.
- MW differences are relatively independent of scene BT for IASI and for AIRS at 1382-1408 cm^{-1}; Differences for AIRS at 1585-1600 cm^{-1} range from ~+0.3K at 200K to -0.1K at 265K.
- SW differences are relatively flat above ~240K; Below ~230K larger differences between all three sensors are observed.
- Consistent with SNO results shown in L. Strow presentation, and reported by L. Wang et al. at NOAA STAR.



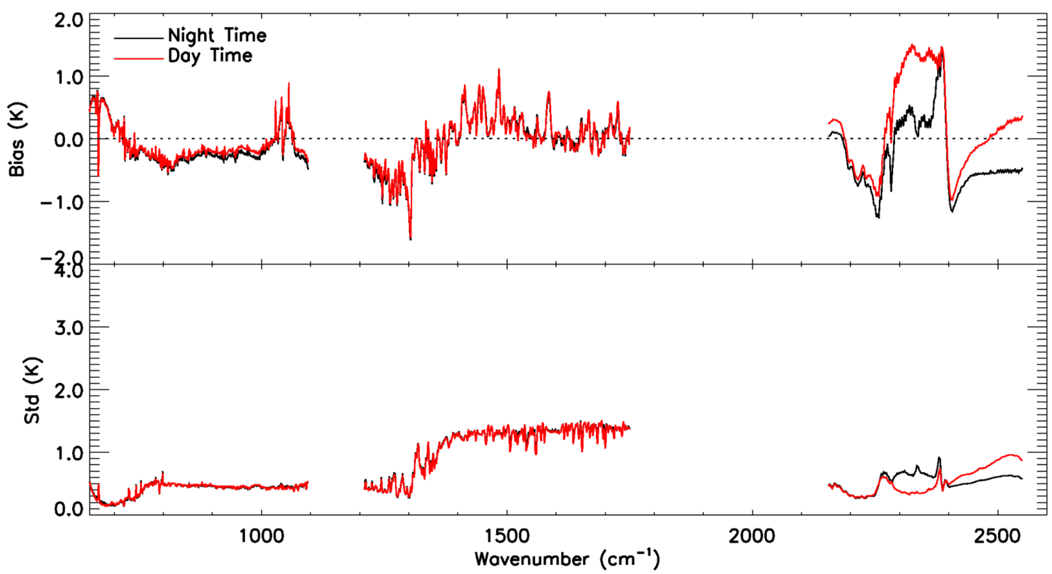
Clear Sky Obs-Calc Analyses

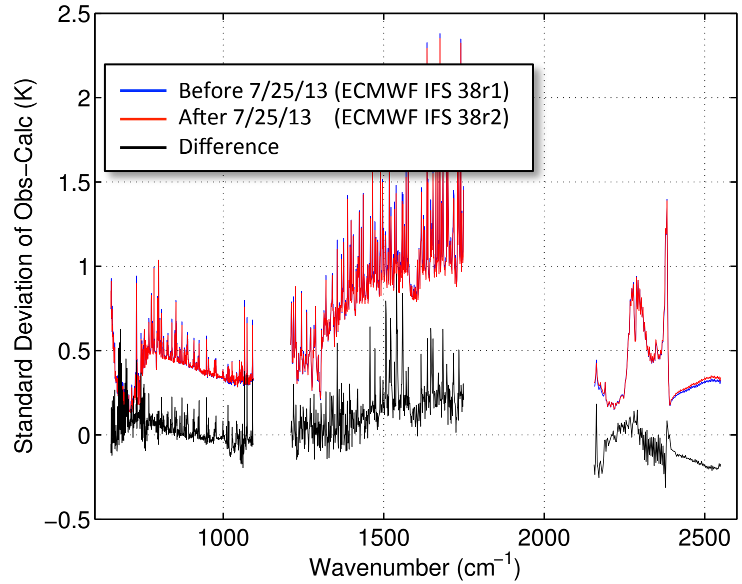
- Behavior of mean biases and standard deviation of obs-calcs are consistent with forward model and atmospheric state uncertainties and imply very good radiometric performance for CrIS.

c/o Larrabee Strow, UMBC:



c/o Yong Chen and Yong Han, NOAA STAR:





Continuing Work:
Calibration and RU Refinements

- Spectral Ringing
- Polarization
- SW band biases

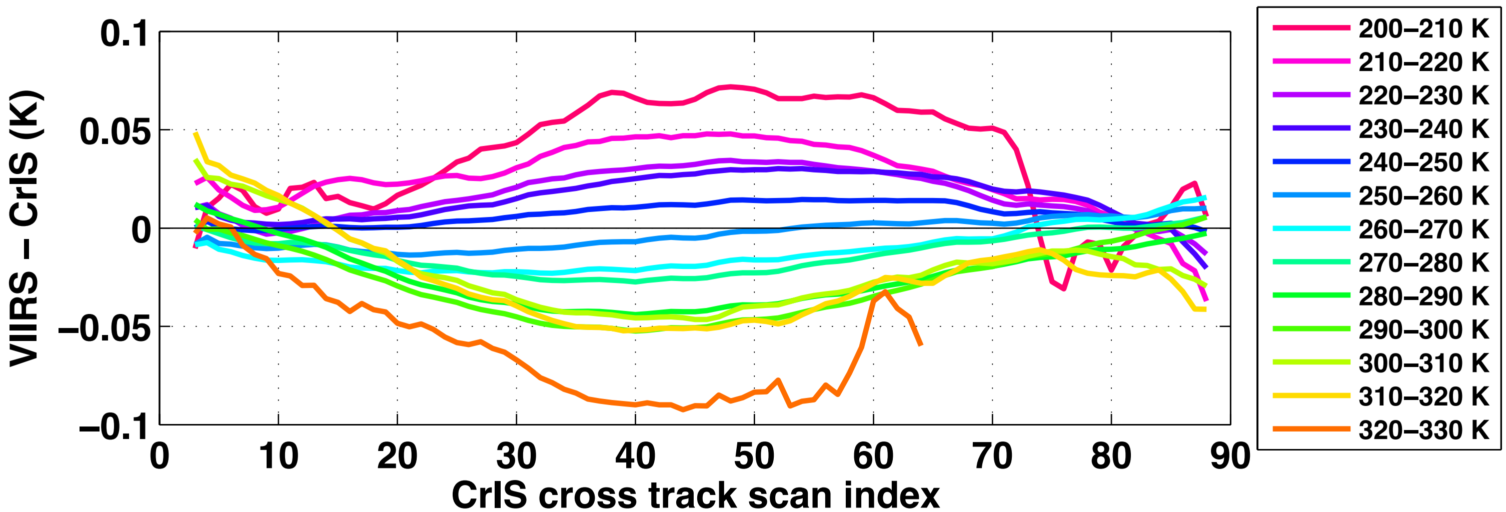
Spectral Ringing

- Considered to be part of the RU budget, but is covered separately in Dan Mooney's talk
- For the large majority of spectral channels, the associated artifacts are very small, and with apodization are negligible everywhere.

Error from Scene Mirror Induced Polarization

- CrIS uses a 45° gold scene mirror that provides low sensitivity to polarization; no correction is included in the SDR algorithm/processing.
- However, it seems almost certain that CrIS should have polarization effects of ~0.1 K for especially warm and cold brightness temperatures in some spectral regions.
- A correction should be developed based on CrIS characterization tests yet to be conducted (measurements of scene mirror degree of polarization, p_r, and interferometer polarization sensitivity, p_t)
- Radiance error dependence ~$2p_rp_t$ $(N – B_{ICT})$
- Suggestions of this type of behavior in CrIS/VIIRS comparisons vs. scan angle:

Scan Angle and Scene BT dependence of VIIRS/CrIS Comparisons at 10.8μm*

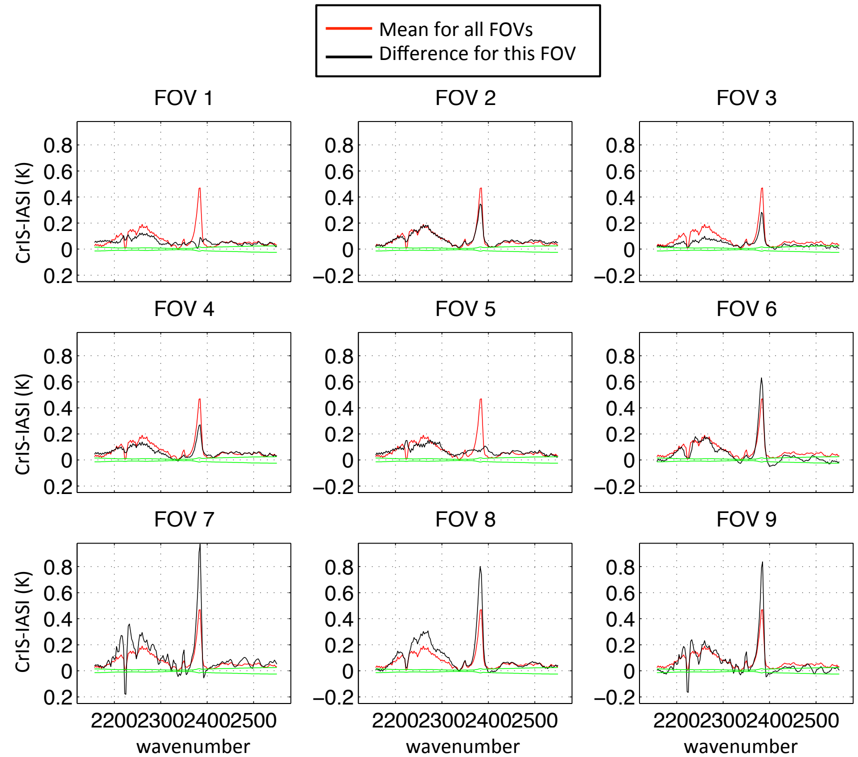


* Biases removed for mean of INDICES 1-10 & 80-90

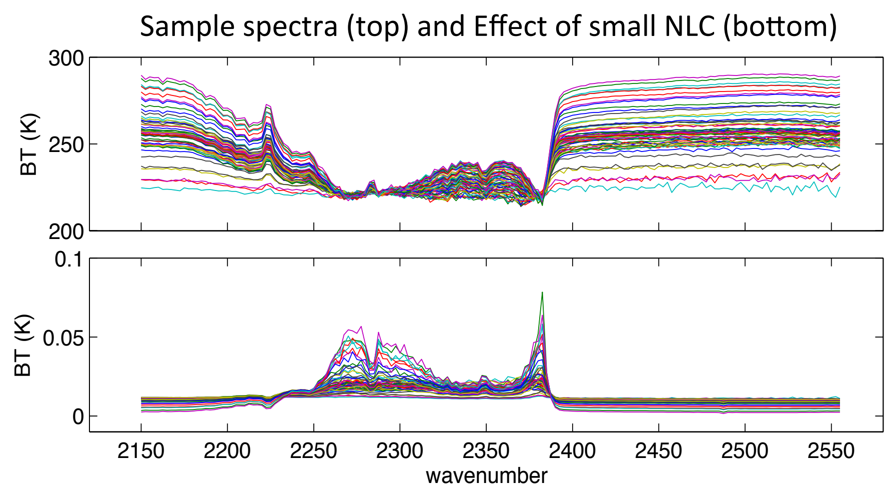
SW Band Biases

- FOV-2-FOV analyses and differences with respect to other sensors suggest small artifacts in the SW band, both in Mean biases and FOV-2-FOV differences.

  E.g. Differences with respect to IASI



- Mechanisms investigated to date:
  - Spectral shift
  - Thermal SP view contamination
  - Solar SP view contamination
  - Noise
  - Polarization
  - ➢ Low level Nonlinearity
    - Displays FOV dependent behavior
    - Has plausible spectral and scene level dependencies



Summary and Conclusions

- On-orbit Radiometric Uncertainty (RU) characterized:
  - Based on careful estimation of 3-sigma uncertainties of the primary calibration parameters and perturbation of the radiometric calibration equation
  - Overall RU estimates are < 0.3K (LW), < 0.15K (MW), < 0.15 K (SW)

- Nonlinearity correction algorithm and coefficients refined
  - Provides improved traceability of the nonlinearity coefficients to the TVAC External Calibration Target
  - Refinements reduce overall RU in LW band and reduce FOV dependence in LW and MW bands
  - SDRs reprocessed using NLC (and ILS) refinements and distributed

- CrIS SDRs and RU estimates have undergone extensive verification/evaluation over a range of representative conditions
  - Periodic aircraft underflights provide high quality, SI traceable verification of the CrIS RU
  - CrIS/VIIRS comparisons imply excellent stability of both sensors, and scene BT dependence further characterized and diagnosed
  - SNOs of CrIS/AIRS and CrIS/IASI show excellent mean agreement and behavior with scene temperature
  - Clear sky obs-calcs imply very good CrIS radiometric performance

- Areas of further refinement have been identified and are under investigation
  - Spectral Ringing
  - Polarization
  - Possible low level SW band nonlinearity